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Simulation and Analysis for Different Speed Control Methods of BLDC Motor Drive

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Abstract* —*The variable speed operation of BLDC motor is required for many applications. In this paper, different speed control methods are compared based on simulation results. Three methods namely variable supply voltage variation to BLDC, current control and vector control are incorporated in simulation and analysis with comparative results. Simulation results help assess performance of BLDC with these three speed control techniques and provide basis for deployment of advanced methods.

Keywords- ***Speed control, BLDC motor drive, current control, vector control***

I. INTRODUCTION

BLDC motor has higher efficiency than that of induction motor and brushed dc motor. Due to many advantages like smooth speed control, compactness, large torque, high power density, lesser maintenance requirements compared to the traditional brushed dc motor, especially three phase permanent magnet brushless dc motor provided with three Hall sensors 120° apart from each other to identify the initial rotor position for the maximum starting torque is used in many applications. Major difference between working of BLDC and BLAC motors in context with speed control is that in BLDC motor concentrated winding is provided with trapezoidal back emf waveform while in BLAC motor distributed winding is provided with sinusoidal back emf waveform [1]. Torque ripple is less in BLAC motor compared to BLDC motor but the harmonics produce in BLAC motor is more due to continuous switching and hence BLDC motor is used widely. Moreover, BLAC drive requires continuously to identify rotor position for precise speed control but BLDC drive requires only discrete signals given by Hall sensors to identify the rotor position because of permanent magnet construction which is in turn comparatively giving low cost of BLDC drive.

The Hall effect commutated motors produce more torque due to lower sensor resolution. Due to high frequency losses caused by higher pulse width modulation carrier frequency and switching losses the trapezoidal drive having higher efficiency compare to sinusoidal drive. Speed is depending upon the number of pole, supply voltage, and back EMF. For change the speed of motor variable dc supply is requiring. The variable dc supply is may be in terms of PWM or any DC converter. There are three ways to change the speed of motor, by changing the number of pole by changing the supply voltage and by changing the back EMF, so once the construction of the motor is made, to change the number of pole is not possible or either it is very difficult.

There are so many DC to DC power electronics converters are available witch gives variable dc voltage for motor speed change. The problem with this converter is that the weight of overall drive is more due to component used in converter is heavy in weight. So, it may be restricted in the weight critical application like in plan and aerospace application. The back EMF produce by the motor is depend on the current passing through the motor and the current passing through the motor is depend on the supply voltage. By changing nature of supply voltage and back EMF the variable speed operation can be done very well. As the most of the motor having the three-winding topology with star connection, the energization of the three winding of the motor is done by the three-phase inverter topology to produce back EMF. Mostly two phase conduction mode is used has having higher power/weight, torque/current ratios. Speed of BLDC motor is depending on the torque produce by the motor and the torque is proportional to the back EMF**.**

Back EMF depends mainly on three factors:

- Rotor angular velocity
- Magnetic field generated by rotor magnets
- The number of turns in the stator windings.

Indirectly for the speed control of the BLDC motor the control of supply voltage is done through the speed control operation

II. SPEED CONTROL OF BRUSH-LESS DC MOTOR

For speed control of BLDC motor there are so many topologies used which is describes as source side or supply voltage control, hysteresis current control, Back EMF control method, direct torque control method. For starting of the BLDC motor identification of rotor position is required to get maximum starting torque. By identifying the rotor position from hall effect sensor the inverter phase is energized as per the table I. When the motor is start, and get the full speed the hall effect sensor output is changed automatic according to the rotor position. The motor speed is depending on the load connected to the motor and supply voltage so for control the speed constant torque production require.

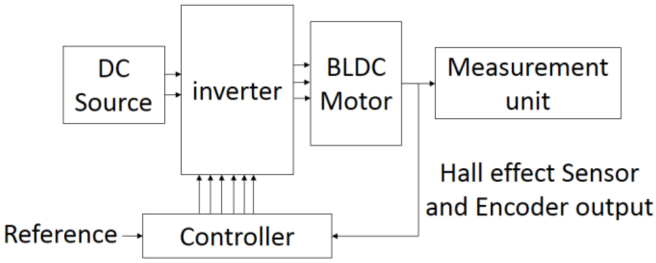

Fig. 1. Basic block diagram for speed control of BLDCM

TABLE-I COMMUTATION SEQUANCE FROM THE HALL SENSOR			
Step	Hall sensor output *Ha Hb Hc*	Switch is in on state	Controlled switch
1	1 0 0	A1	C2
2	1 1 0	C2	B1
3	0 1 0	B1	A2
4	0 1 1	A2	C1
5	0 0 1	C1	B2
6	1 0 1	B2	A1

2.1 Unidirectional Torque Production: [2]

First target that should be satisfied for the keep motor in running condition is to produce the unidirectional torque on the motor shaft. The mechanical power output $T\omega$ is given by $e_{ph}i=T\omega$, where ω is in radM/s. for three phase motor consideration this implies that,

$$T\omega= e_a i+e_b i+ e_c i$$

2.2 Gate decoder

By providing hall effect sensor decoder the gate signal is generated. It is the logic according to which Commutation Sequence is decided. By using the AND, OR, and NOT logic the gate signal is generated from the Table-I. Fig. 2 shows the simulation diagram with the BLDC motor, inverter, Hall sensor decoder and measurement unit. Here 36V DC is supply to the inverter and the motor generates 400rpm speed at no load.

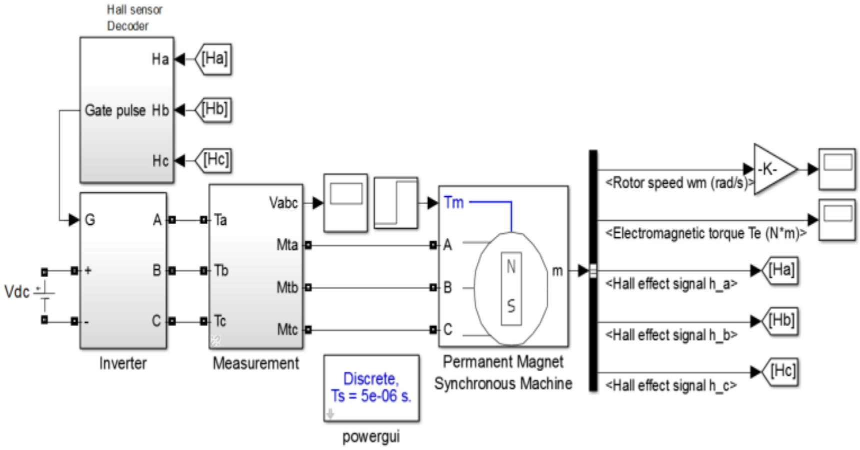

Fig. 2. Simulation diagram for hall sensor decoder

As seen in fig. 3, the input is of the Circuit is 3 Hall Sensor Signal Ha, Hb and Hc and output of the Circuit is 6 different gate pulses. By providing the simple hall decoder circuit for the gate pulse generation it can only start and run the motor. It cannot control or regulate the speed. Table-2 shows the BLDC motor parameter used for simulation. The simulation is run for 2 second, by applying the 0.32 N*m full load at 1 second and it is shows that the speed is reduced from no load speed 4000 rpm to 2875 rpm due to load. For the remedies of it the supply voltage should be increase so the rated speed can achieve at full load.

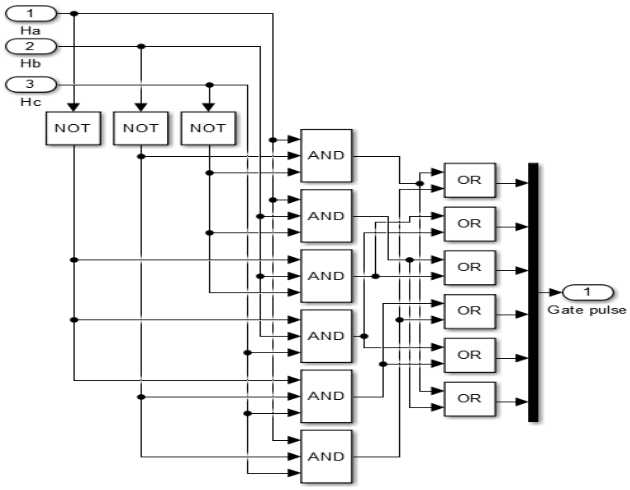

Fig. 3 Hall decoder circuit

TABLE-2 BLDC MOTOR PARAMETERS	
No. of pole	4
Rated voltage	36 V
Rated Torque	0.32 N*m
Phase Resistance	0.5 Ω
Phase Inductance	1.65 mH
Rotor inertia	17.3 $Kg*m^2*10^{-6}$
Rated speed	4000 rpm

when the speed regulation is not important and load is fixed at that time we can use this simple hall sensor decoder circuit to run the motor. It is very simple to execute. By providing only some digital circuitry the motor can run and also the cost of control circuit is also very less.

2.3 Voltage source control

By using source control method, the rated speed at full load can achieve easily. The fig. 4 shows the simulation diagram for the close loop control of BLDC motor. In this simulation pi controller is used to speed control.

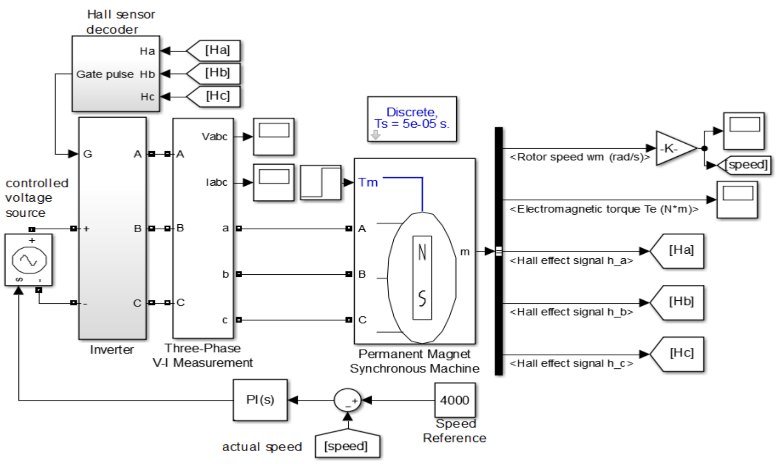

Fig. 4. Simulation diagram for voltage source control using PI controller

For simulation $K_p=0.01$ and $K_i=3.62$. By comparing the actual speed with reference speed the error is generate and by giving this error to the PI controller it generates some reference for controlled voltage source. Controlled voltage source is give the dc voltage to the inverter as per the PI controller value. If the load is increase the supply voltage is increase so the speed is kept constant as the load is decrease the supply voltage is decrease by the controlled voltage source so the speed is remaining constant. Here for constant speed at full load 50V is generated by the voltage source for the inverter. And at no load the voltage is 36V. At no load and full load, the speed is remaining constant at 4000 rpm as shown in fig.5 In this simulation hall sensor decoder is used same as fig. 3. As the fig.5 shows the speed is regulated very well by the source control method. Good response is provided by the PI controller. Then also there is certain limitation over the other methods. As the source control is used some power electronics dc to dc converter is introduce. For the DC voltage control, boost, buck boost, SEPIC converters are used. [3]

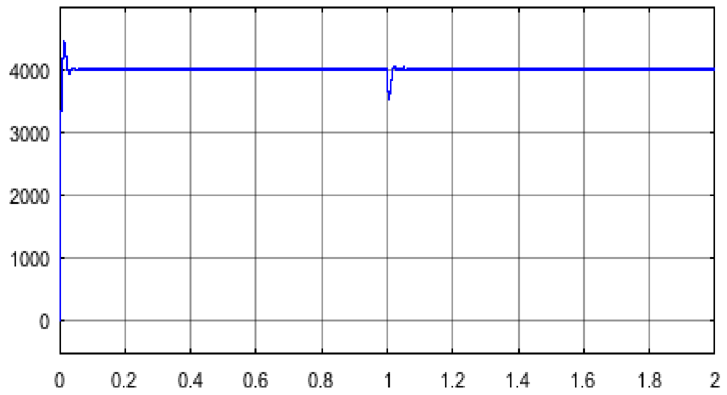

Fig. 5. Speed for PI controller

In this power electronics converters capacitors, inductors, switches are included which is heavy in weight. For some application like aerospace application, air plan application the weight is very critical issue at that time use of this type of strategy is fail. Now a day some recent technology used for this converter in which the capacitor is remove and by changing the control strategy performance of motor can improve. So as the weight is critical issue is restricting the use of dc to dc converter for control of BLDC motor drives. In remedies of it by changing. the three-phase voltage in such a manner that the speed control operation can done without use of the DC power electronics converters. The PWM, Hysteresis current control, space vector modulation, Direct torque control methods are used to control the speed of the motor. In all this method by switching of the inverter the voltage is generated. As the switching is introducing the harmonics and torque ripple is also introducing, which degrades the performance of the motor. By reduce the torque ripple, and improving the switching pattern this problem can be remove.

2.4 current control method

In current control method Hall effect sensor output, torque, and current is taken as input to the current controller for gate pulse generation. The torque is converted into the current by the equation,

$$Iref = \frac{1}{2*P*\lambda} \quad (3)$$

P = No. of pole pair

λ = Flux induce by the magnets

By comparing this current with the actual current the switching pattern is generated. If the actual current is more than reference current, then the switch is off and if the actual current is less than the reference current than switch is on. By this fundamental of current control method, the gate pulse is generated for the three-phase inverter. The basic simulation diagram for this method shown in fig. 6

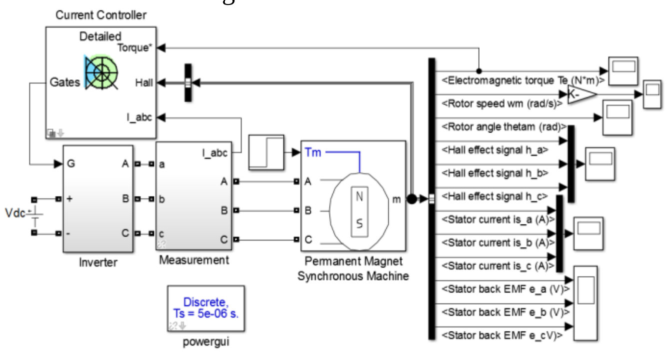

Fig. 6. Simulation diagram for current control method

According to the current comparison the gate pulse is generated. By applying the PWM Switching to this pattern the speed is change. In the current control method, the hysteresis current band is provided for current control and PWM generation.

2.5 Vector control

In vector control of BLDC motor, rotor angle, torque and current is taken as reference to generate the switching pattern. Again, in this method the torque is converted in to the current by using equation 3. By using the transformation this current is transfer in Iabc from the dq0 current. This current is compare with the actual current of the motor. By comparing the current the switching pattern is generated.

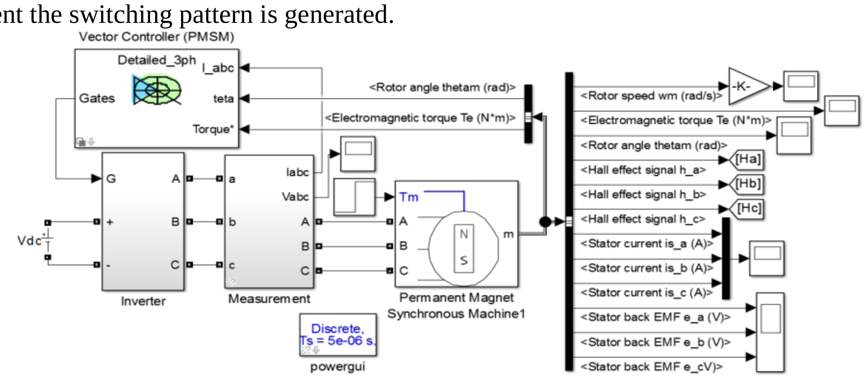

Fig. 7. Simulation diagram for space vector control method

By the using PWM method the gate pulse is generated and it gives to the inverter. In space vector modulation the reference vector is generated and according to the reference vector rotation the sector is selected. The switching pattern is deciding according to selected. The space vector modulation technique is gives good dynamic response. As the load is change the variation in speed is less as compare to other method. By introducing the PI controller in space vector modulation. The space vector modulation gives more efficient use of the bus voltage with compare to the sinusoidal pulse width modulation. The space vector modulation gives 1.15 times more maximum output voltage than the SPWM method.

III. SIMULATION AND RESULT ANALYSIS

The proposed methods were simulated using the MATLAB Simulink. For the BLDC motor require the hall effect sensor output to identify the initial rotor position. As the hall effect sensor is gives the feedback it is not a closed loop control. In fig. 4. the hall sensor decoder is used to start and run the motor.

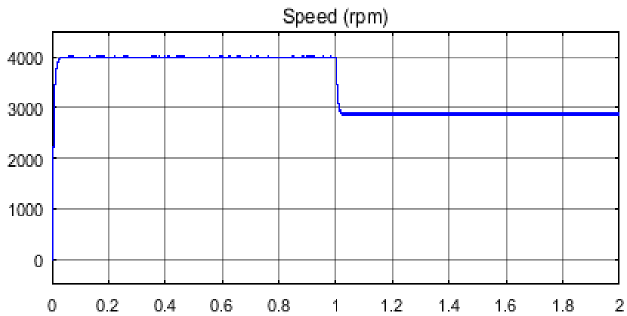

Fig. 8. speed for hall sensor decoder simulation

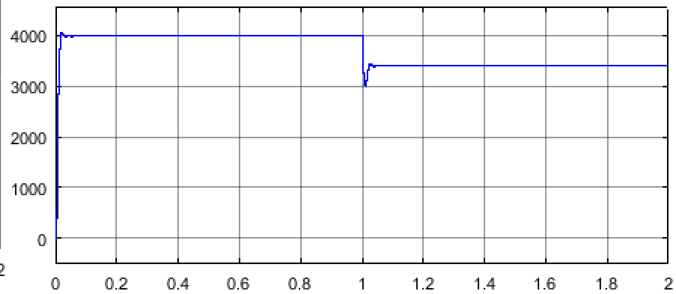
Fig. 9. Speed for current control method

Fig. 8 shows the speed at no load to full load condition. As the load is applying, the response of the speed is very poor. The speed is reduced to 4000 rpm to 2875 rpm. If the speed is very critical issue in any application, then this method cannot be used for those applications. Other method simulated in this paper is current control method. The fig.6 shows the simulation diagram for this method. It shows that the speed is reduce from no load to full load is 4000 rpm to 3410 rpm Here the speed reduce due to the load is less compare to other method but the dynamic response is less. As the load is change the speed fluctuation is more. After some time, the speed is constant.

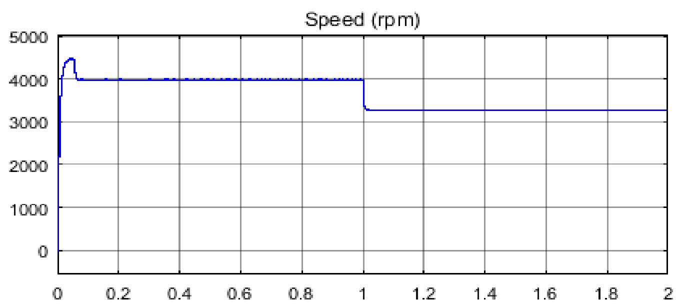

Fig. 10 Speed for Space vector modulation method

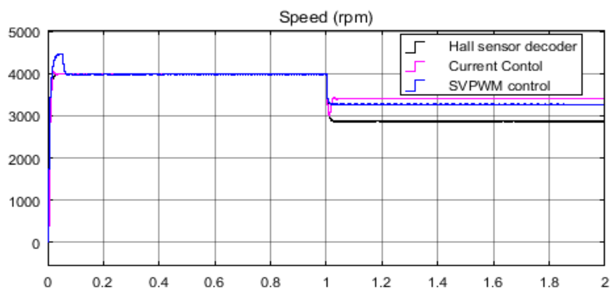

Fig. 11. Speed comparison for hall sensor decoder current sensor and vector control

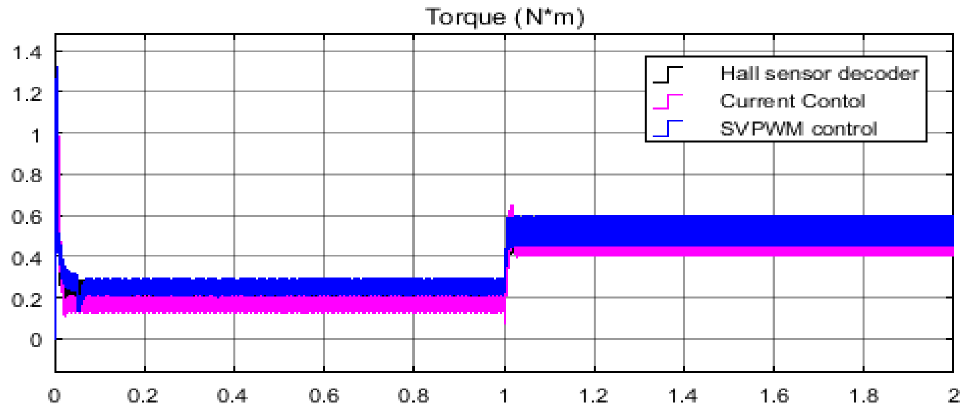

Fig. 12 torque comparison for hall sensor decoder, current control and vector control method

Fig 11. shows comparison of speed for all methods. it shows that change in speed is less in current control method. But torque produce by the vector control is higher than the other. Fig. 12 shows the torque produce by the motor for all three strategies.

CONCLUSION

Different speed control methods are simulated in this paper shows that vector control gives more efficient output as compare to current control and hall sensor decoder. Here voltage source control method gives better output but it having its own dis advantages. By introducing the PI controller to vector control method speed and torque characteristics can be improve.

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